Gallium nitride materials are now a billion dollar industry for optoelectronics. At the same time the robust qualities of GaN make it promising for use in smaller, but no less important, specialist applications such as the nuclear and medical sectors. A case in point is the work underway by James Grant, Andrew Blue and co-workers at the Department of Physics & Astronomy, University of Glasgow. In development are detectors for harsh environments based on SiC and GaN. In parallel they are hoping to produce practical GaN UV detectors for proteomics - the study of proteins, notably that of circular dichrosim (CD).

R Szweda

GaN and SiC detectors for radiation and medicine

"There is a small but very important requirement for efficient detectors in harsh radiation environments,"says James Grant."These are needed for use in critical systems in nuclear reactors and position-sensitive detectors for particle beams and advanced light sources. In particular, for experiments at the CERN Large Hadron Collider (LHC) where they will be subject to fluences of $>10^{15}$ fast hadrons/cm^2. In a proposed upgrade, possibly in 2012, we will require tracking detectors that are able to operate at fluences of 10^{16} fast hadrons/cm^2."This is part of a worldwide CERN based project, entitled RD50.

Silicon shortcomings

Currently silicon technology cannot meet these requirements, so the RD50 collaboration is looking to use other detector sub -strates, notably SiC and GaN."We have investigated the performance of different SiC and GaN materials and irradiated them up to fluences of 10^{16} neutrons and protons/cm^2 with very promising results."

"Michael Moll's paper (also presented at IWORID 6*) entitled 'Development of Radiation Tolerant Semiconductor Detectors for the Super LHC' is a good overview of the subject. I would say at the moment GaN shows some promising results as a rad-hard detector material, but better crystal material is required."

Thus far the team has successfully made and tested SiC and GaN devices. These were Schottky devices on commercially availably materials from Okmetic and Cree. Other materials included bulk GaN from Vilnius University, Lithuania, as well as SI epitaxial GaN detectors made at Tokushima University, Japan.

Standard fabrication methods were used to produce test structures and the resultant detectors were electrically characterised pre- and post-irradiation by performing I-V measurements and CCE measurements. Completed devices were electrically characterised and the charge collection efficiency calculated from pulse height spectra of 241Am alpha particles. SI GaN samples were irradiated with large neutron and proton fluences, as well as a dose of 600 Mrad of 10keV X-rays at Imperial College (ICSTM), London. V-SiC samples were irradiated up to $5x10^{14}$pions/cm^2 by 300MeV/c pions .

Vanadium doped SiC detectors were irradiated to fluences of 10^{12}, 10^{13} and $5x10^{14}$ pions/cm^2. The reverse bias J-V curves from detectors irradiated to different pion fluences, are essentially unchanged for reverse bias voltages up to 300 V. Beyond this the characteristics initially deteriorate at low fluence, but then recover at high fluence. The reverse leakage current was back at the levels found for the unirradiated detector right up to 600 V. The proton irradiated detector shows almost identical J-V characteristics as the un-irradiated detector. Pulse height spectra were measured for vanadium doped SiC detectors,, irradiated and measurements taken to the largest reverse bias voltage, before breakdown, for a given fluence. There was a slight deterioration of the maximum CCE due to irradiation, compared to the maximum CCE of the un-irradiated detectors. The low CCE of 60% of the un-irradiated detectors is attributed to recombination at the vanadium centres in the material.

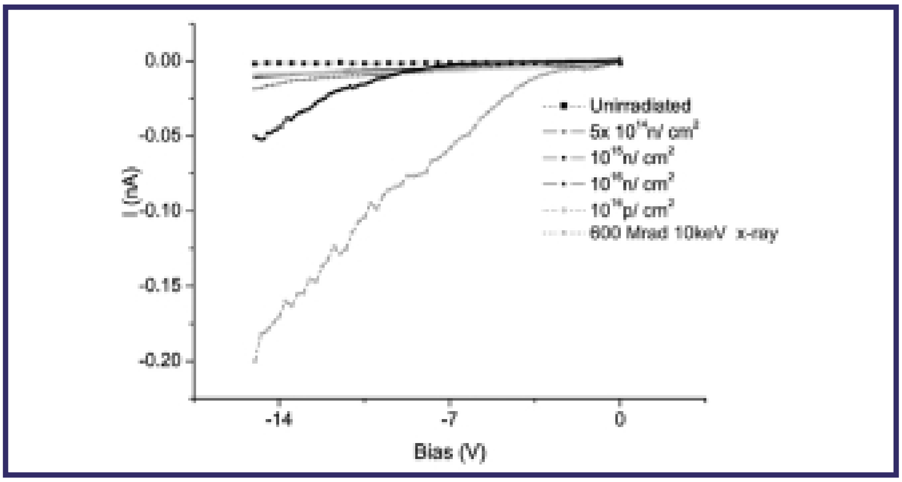


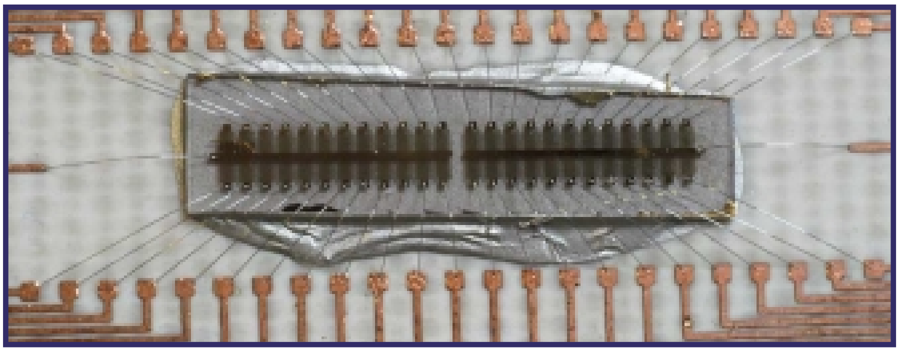
Figure 1. This shows the I-V curves for the irradiated 2micron epitaxial GaN detectors in linear scale.

From the J-V characteristics of a diode fabricated on Okmetic SiC, passivation and bonding of the diodes results in improved characteristics. Preliminary measurements indicate a CCE of 100%, further evidence that the vanadium compensation is responsible for the relatively low CCE of the Cree SiC. "The semi insulating 2 micron epitaxial GaN detectors were irradiated with 1MeV neutrons to fluences of $5x10^{14}$, $1x10^{15}$ and 10^{16}n/cm^2, with 10keV X-rays to a dose of 600Mrad and 24GeV/c protons to a fluence of 10^{16}p/cm^2. Notably, we saw a non-linear increase in leakage current with fluence with the neutron irradiated detectors which has also been reported in other wide bandgap materials. In the case of X-ray irradiation, there was no measured change in the CCE compared to the un-irradiated detector. However, after irradiation to 1015n/cm^2 and to greater fluences, the CCE of the detector dropped to ~10%. CCE measurements are yet to be made on bulk GaN detector."

Even after this promising start, several matters must be resolved before GaN makes the grade as an acceptable detector medium for use in harsh radiation environments. The Glasgow group is working on how to increase the amount of charge collected, for example. Until recently, it has only been possible to manufacture epitaxial SI GaN with a certain active thickness, but thicker wafers with a more suitable active region are now becoming available.

Proteomic UV detectors

Amongst Glasgow's other related investigations into wide bandgap materials are GaN UV detectors for synchrotron-based protein structure studies. With collaborators at the Rutherford Appleton Laboratory, CCLR, AlGaN and GaN have been investigated as UV detector materials for applications in protein structure studies. GaN is becoming a well understood material, leading to stronger interest for other devices. It works well in aggressive environments thanks to its thermal stability and radiation hardness. Also, its 3.4eV direct wide energy bandgap makes it a promising material



The detector is bonded up to a ceramic chip carrier for characterisation. It can can be seen there are two pad/guard ring contacts on the GaN sample.

for photon detection in the UV region. Moreover, addition of Al can lower the cut-off wavelength from 365 to 200nm which means that no short pass filter is necessary for selective UV detection.

Already the Glasgow group has shown that the I-V characteristics of test structures with concentric contacts showed four orders of magnitude greater dark current for the $A_{l0.1}Ga_{0.9}N$ than for GaN. "We went on to make interdigitated metal-semiconductor-metal (MSM) photodetectors on the GaN. The unbiased diodes have three orders of magnitude between dark and photocurrent levels when exposed to UV. The responsivity for diodes with 25 and finger separation, operated in unbiased mode was around 100mA/W and flat over the bandgap. Which means responsivity is in agreement with previous measurements for biased GaN photodetectors."

Using these results, a design for an unbiased GaN detector, to be used for protein structure studies was proposed. An experiment, used to measure how proteins fold, is Circular Dichroism (CD). In CD, an optically active molecule preferentially absorbs one specific direction of circularly polarised light. It is known that each secondary structure of a protein has its own characteristic CD spectrum. To see how a protein folds into its specific compact structure, CD measurements must be at below 260nm. Today, complications arise from the need to measure where the samples absorb strongly below 200 nm, a range of UV not easily accessible using conventional CD instrumentation. Interdigitated metal-semiconductor-metal (MSM) finger-shaped test UV diodes have been fabricated on 2 micron MOCVD grown GaN and $Al_{0.1}Ga_{0.9}N$ on sapphire. Results have been encouraging with responsivity being relatively flat, with good response in the source wavelength region appropriate for synchrotron applications. However, some improvement of a low quantum efficiency will come with better materials, less trapping, better diffusion length of minority carriers and the optimisation of the detector geometry. Although the level of responsivity is low, unlike UV silicon, there is still no need for filters for the visible range. Also unlike diamond, all wavelengths under 365nm are detectable.

UV array detector

Currently, the Glasgow group has "fabricated a 46 channel array detector on GaN that will be used in a CD experiment at Daresbury's Synchrotron source. This detector has not been fully characterised here at Glasgow, but we are hopeful of some further interesting results in due course." A CD experiment using this 46 channel array fabricated by the Glasgow group will be conducted at Daresbury SRS using the higher intensity and range of radiation in the hard UV range offered by a synchrotron source. This 46-channel array of UV diodes will allow measurement over the wavelength range 160-260nm simultaneously via a diffraction grating.

Further reading: * A full paper on wide bandgap semiconductor detectors for harsh radiation environments can be found in the Elsevier journal *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment.* 546, (1-2) 1 July 2005, which is devoted to Proceedings of the 6th International Workshop on Radiation Imaging Detectors - Radiation Imaging Detectors. 2004. Related papers of interest include detectors based on other III-V semiconductors, SiC and diamond radiation detectors, state of the art on epitaxial GaAs detectors and a digital X-ray portable scanner based on monolithic semi-insulating GaAs detectors.